# Improving Air-Sea Coupling Parameterizations in High-Wind Regimes

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## LONG-TERM GOAL

The long-term goal of this PI team is to understand the physical processes of the air-sea interaction and coupling of the atmosphere-ocean system in high-wind maritime regimes, with a particular emphasis on hurricanes, and to determine the changes that must be made to the coupled atmosphere-wave-ocean models in order to simulate the coupled boundary layers under extreme wind conditions.

## OBJECTIVES

The main objectives of this study are 1) to develop improved subgrid-scale (SGS) parameterizations for modeling the atmosphere boundary layer (ABL) structure in high-wind regimes using a large-eddy simulation (LES) approach and explore the effects of sea spray on the ABL through LES experiments, 2) to improve drag coefficient calculations for high-wind conditions by parameterizing "spectral tails" (wavelength < 10 m) unresolved by the current wave models, 3) to test the sensitivity of mixing schemes in the ocean mixed layer (OML) and examine the effects of the ocean waves on the OML dynamics, and 4) to develop atmosphere-wave and atmosphere-ocean generic couplers to allow the flexibility of testing various physical parameterizations and different models in the coupled system.

## APPROACH

Our current focus is to study the nature of coupled atmosphere-ocean boundary layers and heat and momentum exchange at the air-sea interface in hurricanes. The extreme high winds, intense rainfall, large ocean surface waves, and copious sea spray push the surface-exchange parameters for temperature, water vapor and momentum to untested new regimes. We will develop improved parameterizations of subgrid-scale processes, air-sea exchange coefficients, and surface fluxes in coupled atmosphere-wave-ocean models with high-resolution (~1-2 km grid spacing) that can resolve the hurricane eyewall structure. The RSMAS/UM PI team is focusing on the effects of ocean wave "spectral tails" on drag coefficient, wind-wave coupling, and ocean mixed layer parameterizations. In a closely related project (supported by ONR under grant N00014-03-1-0473), the PI (Chen) works with Drs. W. Frank and J. Wyngaard at PSU to develop improved parameterizations of subgrid-scale processes in ABL. The methodology is to use a Large-Eddy Simulation (LES) initialized for hurricane-like conditions, including very high winds, sea spray, and the effects of waves at the lower boundary. These parameterizations would then be installed and tested in the coupled atmosphere-

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wave-ocean models like the coupled modeling system at RSMAS/UM and the U. S. Navy's COAMPS. We will work closely with the CBLAST-Hurricane PI team (Dr. P. Black et al.) taking observations during the CBLAST-Hurricane field program and using the data to evaluate/validate our coupled modeling results.

**WORK COMPLETED**

During the year 2002-2003, we have established several key steps toward developing a set of new coupling parameterizations and numerical couplers for a fully coupled atmosphere-wave-ocean modeling system for hurricane research and prediction. The components of the coupled systems are the PSU/NCAR MM5, WAVEWATCH III (WW3), and the University of Miami HYCOM. Progresses are made in the three main areas. First, we have developed a wind-wave coupler to couple MM5 and WW3. Two different coupling parameterizations, namely non-directional and directional stress coupling, with and without the "spectral tails" parameterization, are tested in coupled simulations of Hurricane Floyd (1999) and Hurricane Bonnie (1998). Using a vortex-following, four-level nested grids MM5, we are able to conduct a 5-day long simulation to capture the evolution and the landfall of the two hurricanes at 1.67 km grid resolution on the inner-most domain (Rogers et al. 2003). The NECP global analysis fields and the high-resolution (~9 km) AVHRR Pathfinder analysis (Chen, et al., 2001) are used to initialize MM5 and provide continuous lateral and lower boundary conditions. The results are summarized in Chen et al. (2002). We have evaluated/validated model simulated surface wave spectra with observations both over the open ocean and at the landfall (Walsh et al. 2001). Second, to investigate the impact of the upper ocean circulation, especially the hurricane induced cold wake, on hurricane intensity, we used a relatively simple upper ocean circulation model developed at WHOI by Price et al. and coupled it to the MM5. This will allow us to develop and test the coupler while getting the more complex HYCOM ready for the hurricane simulations. Third, we have added new vertical mixing submodels to HYCOM, and has validated the performance of the model and the hybrid vertical coordinate adjustment algorithm using all available vertical mixing algorithms.

Over the past year, development and validation of HYCOM proceeded on a number of fronts. A new vertical mixing model, specifically the level-2 turbulence closure model developed at the NASA Goddard Institute of Space Studies (GISS) has been added as the fifth primary vertical mixing model. The nesting capabilities have been thoroughly tested. Realistic basin-scale Atlantic simulations and simulations of the Intra-Americas Sea have been performed at high resolution (1/12 degree), both with and without assimilation of satellite altimetry, from 1999 to the present. These fields are now available to provide the initial and boundary conditions for simulations of the ocean response to individual hurricanes. The use of simulations where altimetry has been assimilated is important because this will insure that ocean currents, fronts, and eddies, including the associated upper-ocean heat content anomalies, are accurately represented. Currently we are in the process of configuring the ocean model in the coupled framework. We are also testing the high-resolution (1/12 degree) HYCOM using the coupled MM5-WW3 simulations of Hurricane Floyd (1999) and Hurricane Bonnie (1998) to investigate the ocean response to one or more hurricanes using the different vertical mixing choices available in HYCOM. A subregion will be selected for each storm within which the model will be run first at 1/12-degree resolution and later at 1/24-degree resolution. Model sensitivity to vertical mixing choice will be quantified and the mixing models that provide the most realistic results will be identified. Efforts will be made to improve individual mixing models based on the results by modifying the algorithms or adjust model parameters. The sensitivity of the model response to vertical resolution will also be explored.

## RESULTS

We have conducted a number of coupled MM5-WW3 simulations to investigate the sensitivity of model simulated hurricane intensity to various wind-wave coupling parameterizations. Fig. 1 shows the simulated minimum sea level pressure (SLP) for Hurricane Floyd (1999) using three different wind-wave couplings 1) roughness length from a simple friction velocity relationship, 2) wave-age dependent roughness length, and 3) directional stress coupling with our spectral-tail parameterization. The storm intensity varies by 15-20 m $s^{-1}$ with different wind-wave couplings. The directional stress coupling seems to be the closest one to that observed from the best track record.

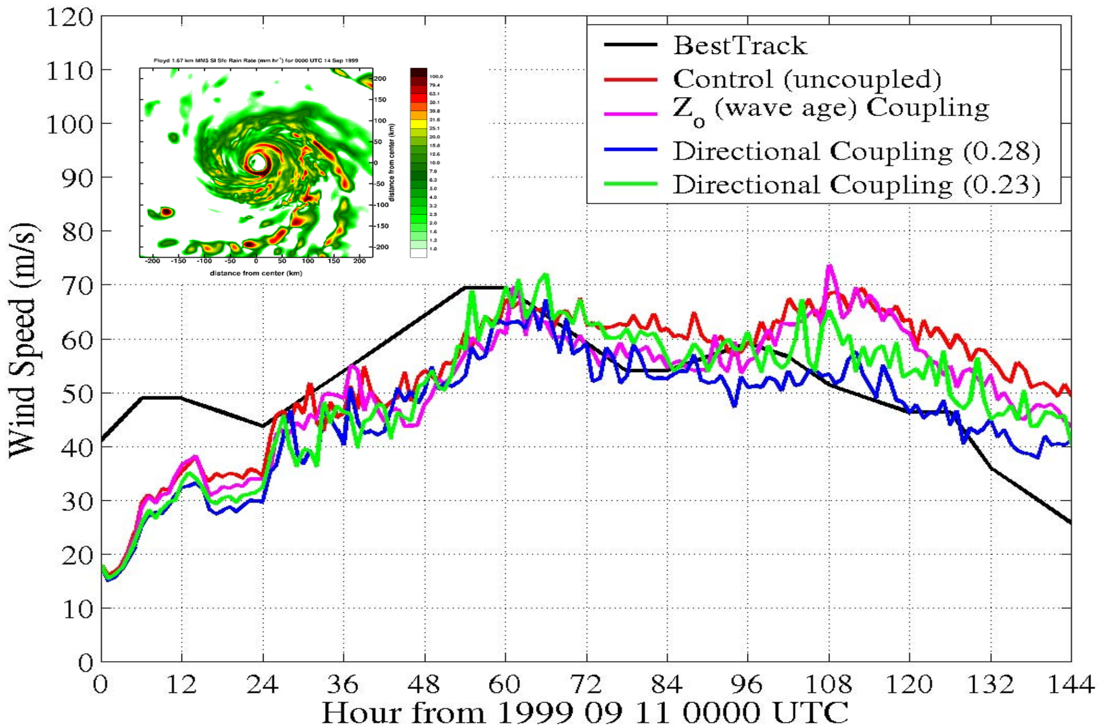


***Fig. 1 Coupled MM5-WW3 simulations of storm intensity for Hurricane Floyd (1999) using three different wind-wave coupling parameterizations.***

resolution, inadequate surface and boundary layer formulations, and lack of full coupling to the ocean. This project will provide improved physical parameterizations for the coupled atmosphere-wave-ocean models at very high spatial resolution. It will make a significant contribution to improve hurricane intensity predictions.

Hurricane intensity is known to be affected by changing of SST and upper ocean heat content due to the storm-induced high winds. However the previous studies have shown a relative minor impact using coupled atmosphere-ocean model. One of the main reasons for the low impact is that the models had relative low spatial resolution, which cannot resolve the hurricane eyewall where the high wind is located. In our high-resolution (1.67-km grid spacing) simulation, the eyewall is explicitly simulated. The air-sea coupling becomes an extremely important factor contributing to the prediction of hurricane intensity. Fig. 2 shows the impact of the atmosphere-ocean coupling on Hurricane Bonnie (1998).

The uncoupled MM5 simulation overestimates the storm intensity without the coupled ocean circulation.

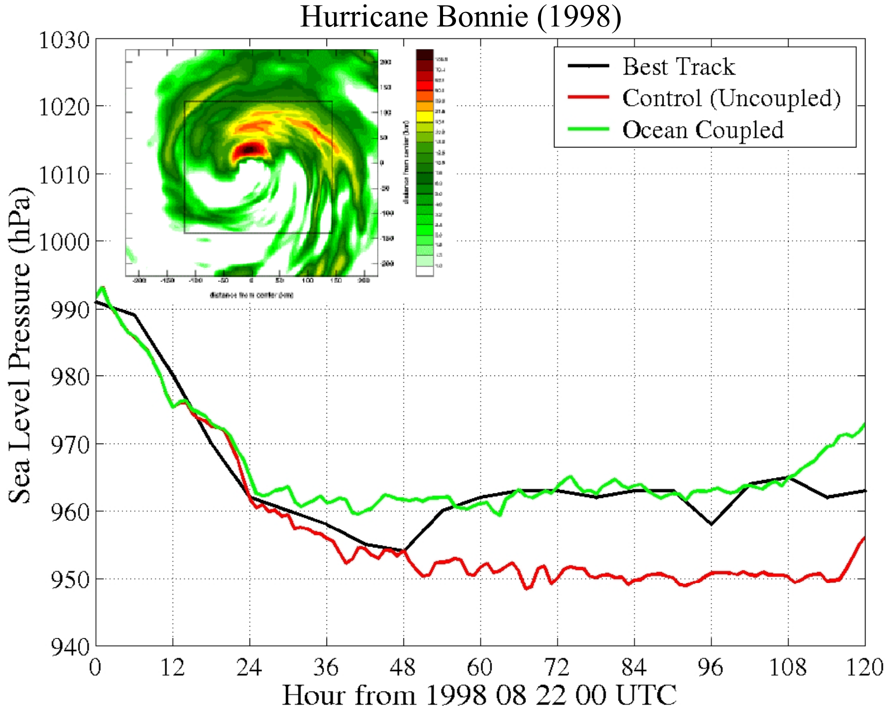


***Fig. 2 Comparison of uncoupled MM5 and coupled MM5-PWP 3D ocean model simulations of storm intensity for Hurricane Bonnie (1998).***

**IMPACT/APPLICATIONS**

Over the last a few decades hurricane track forecasts have improved significantly, whereas very little progress made in hurricane intensity forecasts. The lack of the skill in the intensity forecasts can be attributed, in part, to deficiencies in the current operational prediction models: insufficient model resolution, inadequate surface and boundary layer formulations, and lack of full coupling to the ocean. This project will provide improved physical parameterizations for the coupled atmosphere-wave-ocean models at very high spatial resolution. It will make a significant contribution to improve hurricane intensity predictions.

**TRANSITIONS**

We will assist in the transitioning of the completed parameterizations to operational coupled modeling systems (e.g., COAMPS). These new parameterizations developed at RSMAS/U.Miami and Penn State will be made available for all ONR CBLAST PIs.

**RELATED PROJECTS**

Related projects include the NSF/NOAA/ONR USWRP on Rainfall of Hurricanes at Landfall (S. Chen), the ONR coupled boundary layers (S. Chen, W. Frank, J. Wyngaard), the NASA/JPL

QuikSCAT (S. Chen), ONR HYCOM Consortium for Data Assimilative Ocean Modeling (E. Chassignet, G. Halliwell, et al.), and ONR CBLAST-Hurricane (P. Black et al.).

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